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Original Article

Determination of Some Fruit Quality Characteristics of Azman Banana Cultivar at Different Ripening Stages

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ABSTRACT

Banana (*Musa cavendishii* L.), a member of the Musaceae family, it is a tropical climate plant and an important fruit with high nutritional value that can only grow in the subtropical climate zone.Banana, widely consumed in the countries where it is cultivated, has recently been extensively grown in the coastal regions of our country as well. Due to its richness in bioactive phenols, antioxidants, and potassium, it is recognized as an excellent source of nutrition.mThis study investigated the effects of different ripening stages on the bioactive compounds in bananas of the Azman cultivar. The results revealed that bioactive compounds varied depending on the stages of ripening. The study determined that L*, a*, and b* color values increased proportionally with the ripening duration. It was found that green bananas had lower total phenolic and antioxidant contents compared to ripe fruits. Furthermore, the soluble sugar content (sucrose, glucose, and fructose) in Azman bananas increased during the ripening process. While the levels of citric, malic, and succinic acids increased with ripening, the content of oxalic acid decreased.

Key words: Banana, Dpph scavenging activity, HPLC, Organic acids, Sugars, Total phenol content.

Azman Muz Çeşidinin Farklı Olgunlaşma Aşamalarında Bazı Meyve Kalite Özelliklerinin Belirlenmesi

ÖZ

Musaceae familyasının bir üyesi olan muz (*Musa cavendishii* L), tropik iklim bitkisi olup, ancak subtropik iklim kuşağında yetişebilen besin değeri yüksek önemli bir meyvedir. Yetiştirildiği ülkelerde geniş bir tüketim alanına sahip olan muz bitkisi, son yıllarda ülkemizde de kıyı kuşağında yaygın olarak yetiştirilmeye başlanmıştır. Biyoaktif fenoller, antioksidanlar ve potasyum açısından zengin olması nedeniyle iyi bir besin kaynağı olarak kabul edilmektedir. Bu çalışmada, Azman muz çeşidine ait muz meyvelerinde olgunlaşmanın farklı aşamalarının biyoaktif bileşikler üzerindeki etkisi araştırılmıştır. Sonuçlar, biyoaktif bileşiklerin farklı olgunlaşma aşamalarına göre değiştiğini göstermiştir. Çalışmada, L*, a* ve b*, renk değerlerinin olgunlaşma süresi ile orantılı olarak arttığı belirlenmiştir. Yeşil muzların olgun meyvelere göre daha düşük toplam fenolik ve antioksidan içeriğine sahip olduğu tespit edilmiştir. 'Azman' muz meyvelerinde çözünebilir şekerlerin (sakkaroz, glikoz ve fruktoz) içeriği meyve olgunlaşmasıyla birlikte artmıştır. Sitrik, malik ve süksinik asit içeriği meyve olgunlaşmasıyla birlikte artarken, oksalik asit azalmıştır.

Anahtar kelimeler: : Dpph Süpürme Aktivitesi, HPLC, Muz, Organik asitler, Şekerler, Toplam fenol içeriği.

INTRODUCTION

Banana (*Musa cavendishii* L.) is a fruit in the family Musaceae of Scitamineae. The Musaceae family has two main genera, Musa and Ensete. The genus Musa includes the edible cultivated species and the wild species Esnete, found in the forests of East Africa. The banana plant is native to the islands between South China, India, and Australia. Of the bananas cultivated in the world, 41% are "Cavendish", 14% are "Gros Michel", 21% are "Plantain" and 24% are cooking bananas.

Banana fruit is considered a good source of nutrients as it is rich in bioactive phenols, antioxidants, and potassium (Williams, 1995). Banana fruit is also rich in vitamins. It is important for human health and nutrition and has a high energy value. Thanks to its simple digestion and flavor, it is consumed by all age groups in our country. According to Food and Agriculture Organization (FAO) statistics, Asia is the largest banana producer, accounting for 54.4 percent of world banana production. According to FAO 2023 data, India ranks first with 36.614.000 tonnes, China second with 12.062.222 tonnes, Indonesia third with 9.335.232 tonnes, and Brazil fourth with 6.855.724 tonnes. In 2023, world banana production was 139.277.894 tonnes (Anonymous, 2025a). Although the latitudes and longitudes of our country are outside the banana growing areas, it is noteworthy that bananas have increased significantly in our country in recent years. According to TUIK data, banana production in Turkey for 2024 was realized as 875.000 tonnes (Anonymous, 2025b).

Several studies on banana pulp have examined its properties, ranging from its use as a food supplement to the extraction and recovery of starch, cellulose, and bioactive phytochemicals (Singh et al., 2016). Usually, only ripe pulp is consumed due to its high sugar content and sensory aspects. However, green fruit is also consumed in some regional dishes due to its high starch content. In addition, the inclusion of green fruit flour in some products such as biscuits, fiber-rich bread, and edible films is increasing. Consumption of green bananas (peel and pulp) is beneficial for human health due to their high content of resistant starch, which acts as food fiber in the body (Rodríguezambriz et al., 2008; Oliveira et al., 2015). In addition, banana flour can be an important source of polyphenols, compounds that are considered natural antioxidants (Vergara-Valencia et al., 2007). Banana is a tropical plant that can protect from the oxidative stress caused by high intensity of sunlight and elevated temperature by raising its antioxidant ability (Kanazawa and Sakakibara, 2000). Banana fruits contain many antioxidant compounds such as vitamin E, β-carotene, vitamin C, and flavonoids in both pulp and peel tissues. Macheix et al. (1990) reported that banana pulp contains high levels of total phenolics and tannins. In addition, some enzymes play an important role in increasing the antioxidant capacity of banana pulp (Someya et al., 2002).

Fruit ripening is a highly coordinated, genetically programmed, and irreversible process involving several physiological, biochemical and organoleptic changes such as chlorophyll degradation, increased respiration, ethylene production, biosynthesis of anthocyanins, essential oils, carotenoids, flavor and aroma compounds and activation of cell wall degradation (Prasanna et al., 2007). Banana fruit is a climacteric fruit and respires after harvest, resulting in ripening and browning of the skin color and a decrease in fruit flesh firmness due to ethylene production (Seymour, 2012). Banana fruit has a maximum shelf life of 6 to 8 days after starting to ripen during post-harvest storage (Huang et al., 2014). With the increase in banana production and consumption, knowledge in post-harvest handling is required. A range of pre-harvest and post-harvest factors influences physico-chemical properties, nutritional value, and antioxidant components in fruits. (Xie et al., 2016). Understanding the physico-chemical properties and nutritional characteristics of fruit is important for the design of cost-effective and efficient post-harvest handling equipment, and optimization of bioprocesses in functional food production and pharmaceuticals. Currently, there is a lack of scientific knowledge on the key nutritional changes that occur during the ripeness of banana (*Musa cavendishii* L.) cultivars grown in Türkiye. These fruits do not reach maturity at the same time, green/yellow to ripe fruits coexist on the same tree. Typically, during harvesting, all fruits regardless of their ripening are often picked together. The study aimed to determine rind color, total phenol content, total antioxidant capacity, sugars, and organic acid in different maturity stages across Azman banana cultivar grown in Adana province of Türkiye.

MATERIALS AND METHODS

Plant Material

Plants of 'Azman' banana cultivar grown under greenhouse conditions in Sarıçam district of Adana province, Turkey were used as plant material. Fruits were harvested as shown in Figure 1 and analyzed in three stages: first stage, third stage, and fifth stage.

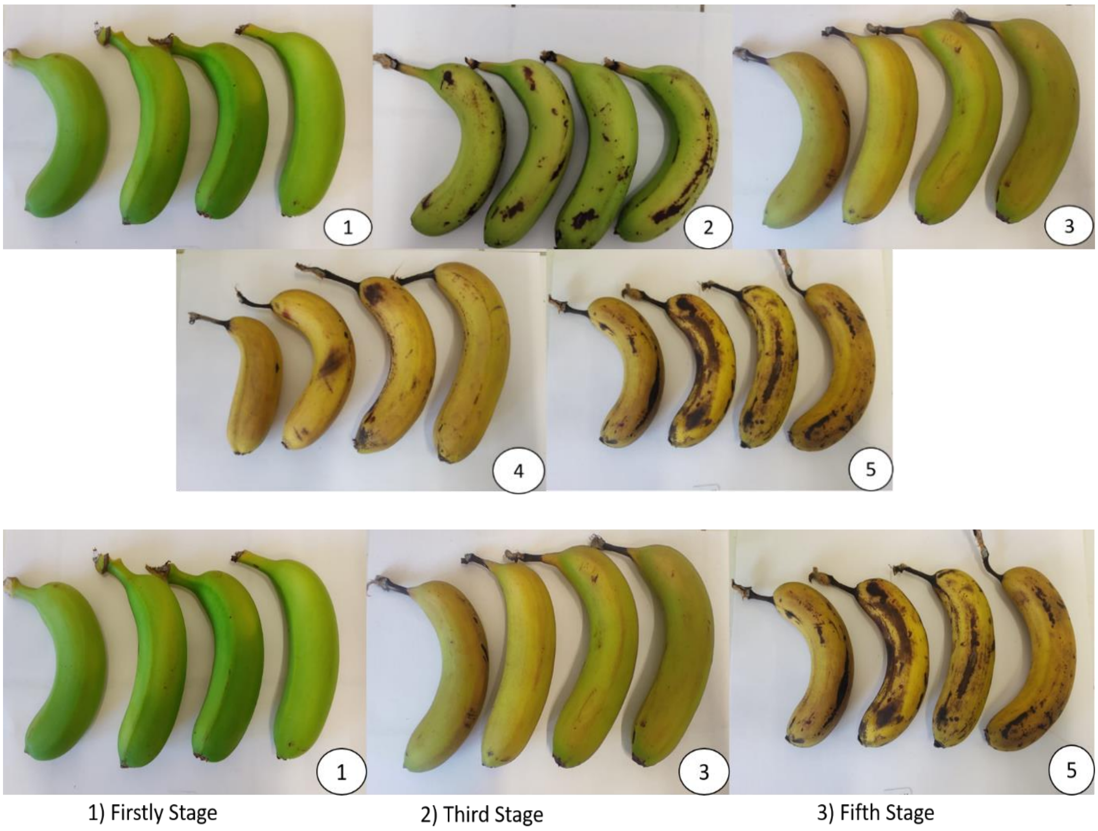

Figure 1: Different ripening stages of banana fruit.

Method

The fruits harvested at different periods in the greenhouse were immediately brought to the Instrumental Analysis Laboratory of the Department of Horticulture, Faculty of Agriculture, Çukurova University. The fruits of Azman banana cultivar were peeled and the pulp was homogenized. It was then stored at -20^{o}C until analysis. Peel color, total phenolic matter, antioxidant activity, organic acids, and individual sugars were analyzed by spectrophotometer and HPLC (High Performance Liquid Chromatography) with 3 replicates, respectively.

Color Measurement

The fruit color of different maturity stages Azman banana cultivar measured as L, a*, b* using Minolta chromometer (Minolta 86 Co model CR-400, Tokyo, Japan) and calculated by a formula and given also as C and hue (h°) values of the outer color of the The device was calibrated with a standard white calibration plate before the measurements. Croma (C*), which determines the saturation and vividness of the color, and Hue angle (hue*), which determines the basic components of color (red, yellow, blue, and green), were calculated from the a* and b* values obtained fruits (Kılıç et al., 2021).

$C^* = (a^{*2}+b^{*2})^{1/2}$, $hue^* = \tan^{-1}(b^*/a^*)$

Determination of total phenol

After homogenizing and weighing banana fruit samples at different stages of ripeness, the total phenolic content of the juice was determined colorimetrically using Folin Ciocalteu reagent (Spanos, 1990). The absorbance value at 760 nm wavelength in the spectrophotometer (MultiskanTM GO microplate spectrophotometer) and the calibration curve created with gallic acid were used to calculate the metric values. The results are given in milligrams of gallic acid equivalent per 100 grams of weight (mg/GAE 100 g).

Determination of total antioxidant capacity

Banana fruits were weighed and homogenized after harvesting and the total amount of antioxidants in the juice was determined using the DPPH (1,1-diphenyl 2 picrylhydrazyl) method proposed by Brand Williams (1995) with slight modifications. DPPH was prepared fresh at 0.06 µM. The mixture was blended for 1 minute before being kept in the dark for 30 minutes at room temperature. Then, 1950 µL DPPH- was added to 50 µL banana sample. Absorbance of mixture was measured at 515 nm. Radical scavenging activity %DPPH inhibition was calculated using the following equation:

%Inhibition = 100 × [(Abs blank (t = 30)) − (Abs sample)]/[(Abs blank (t = 30))].

Liquid chromatographic analysis of sugars

Glucose, fructose, sucrose, and total sugar contents at different ripening stages of banana fruit samples were determined using the HPLC technique, following the method developed by Crisosto et al. (1997).

Determination of organic acids

Organic acids in different ripening stages of banana fruits were determined by the HPLC analysis (Bozan et al., 1997). The malic, oxalic citric and succinic acid contents in banana fruit samples were determined.

Statistical analysis

The experiment was performed with a completely randomised experimental block design in three replications for one cultivar and three stages (Green, Medium Ripe, Over Ripe) in each replicate. Data were processed with the SPSS package program version 23.0 (SPSS Inc., Chicago, IL, USA). All data were presented as the mean ± standard error (SE) and analyzed by one-way analysis of variance (ANOVA). Differences were considered significant at p <0.05 (Steel et al., 1997).

RESULTS AND DISCUSSION

Results of fruit skin color of banana cultivars are presented in Table 1. In the study, there were significant differences in skin color (L*, a*, b*, Croma* and Hue*) during the ripening period. Fruit skin color (L*, a*, b*, Croma* and Hue*) was found to be 55.67, -4.20, 35.87, 36.10, 83.39 in green banana (first stage), 63.30, 0.23, 43.20, 43.20, 89.72 in medium ripe (third stage) banana and 64.53, 4.13, 44.30, 44.53, 95.44 (fifth stage) in overripe banana. Color change in the fruit is due to the breakdown of chlorophyll and color change increases with chlorophyll degradation as ripening progresses (Knee, 1972). In the study, significant changes occurred in color values during storage. It was determined that color values increased in proportion to ripening time. The L*, a*, b* values we found in this study were similar to Alkarkhi et al. (2011) and Watharkar et al. (2020).

Table 1. At different stages of ripeness Color Measurement values of banana samples

Ripeness stages	L*	a*	b*	Croma*	Hue*
First Stage (Green)	55.67±1.67b	-4.20±1.61c	35.87±1.19b	36.10±1.03b	83.39±2.21c
Third Stage (Medium Ripe)	63.30±0.84a	0.23±1.11b	43.20±1.54a	43.20±1.53a	89.72±1.51b
Fifth Stage (Over Ripe)	64.53±1.59a	4.13±0.42a	44.30±0.93a	44.53±0.89a	95.44±0.79a
Sig	0.02	0.02	0.01	0.01	0.01

The difference between means denoted by the same letter is not statistically important (p<0.05).

As a result of this study, it was found total antioxidant and phenolic content of banana samples have changed in different ripening periods. In addition, the statistical differences in the results of TPC and DPPH radical scavenging activities (P < 0.05) between banana samples were found to be significant. Total phenol was found to be 27.66 mg GAE /100g in green banana (first stage), 45.02 mg GAE /100g in medium ripe (third stage) banana, and 90.12 mg GAE /100g (fifth stage) in overripe banana. When antioxidant contents were compared, the highest %DPPH radical scavenging value was found in the fruit of the ripe banana (80.95%), while the lowest %DPPH radical scavenging value was found in the fruit of the medium ripe banana (38.80%) (Table 2). We determined that green bananas have lower total phenolic content than overripe fruits. Bilgin et al. (2022) found that the total phenolic and antioxidant content of 'Grand Naine' banana fruits at different ripening stages increased at green (first stage) and extreme ripeness (seventh stage) and decreased at medium ripeness (fourth stage). Fatemeh et al. (2012) also showed that green bananas have lower total phenolic content than ripened fruits. The extracts' radical scavenging abilities (DPPH inhibition) ranged from 26.55 to 52.66 percent (first stage to seventh stage). González-Montelongo et al. (2010) compared different solvents for DPPH scavenging activities. They found that acetone:water extracts had the highest antioxidant activity compared to the other solvents studied, with a factor of 1.3-1.9 (methanol) and 25-35 (acetone) for the DPPH assay and a factor of 2-4 (methanol) and about 10-35 (ethanol, acetone and water in “Grande Naine” banana cultivar and ethanol, acetone and water in “Gruesa”) for the ABTS+ assay. Total antioxidant activity increased with ripening and decreased rapidly with senescence in the banana cultivars studied. In the study, an increase in total phenol and antioxidant value was observed as the ripening time of the fruit increased. Ngoh Newilah et al. (2008) obtained similar results in hybrid bananas where total phenolic content increased with ripening and decreased with time at the full ripening stage. The findings of this study are similar to the literature.

Table 2. At different stages of ripeness, total phenolic content (mg/ GAE 100g) and DPPH (%) radical scavenging values of banana samples

Ripeness stages	DPPH radical scavenging%	Total Phenol
First Stage (Green)	38.80±2.84c	27.66±0.85c
Third Stage (Medium Ripe)	65.98±1.43b	45.02±1.54b
Fifth Stage (Over Ripe)	80.95±1.46a	90.12±7.70a
Sig	0.02	0.01

The difference between means denoted by the same letter is not statistically important ($p<0.05$).

The HPLC sugar profiles show that sucrose is the major sugar, followed by fructose and glucose in all banana samples (Table 2). Especially fructose and glucose contribute both as energy sources and in terms of taste and flavor (Çalışkan and Bayazıt, 2012). Ripe bananas contain about 20-25% starch by fresh weight (Do Nascimento et al., 2006). During ripening in banana fruit, one of the main mechanisms causing fruit softening is starch breakdown, (Prasanna et al., 2007), which also provides carbon for sucrose synthesis (Saraiva et al., 2013). The content of soluble sugars (sucrose, glucose and fructose) in the 'Azman' banana increased with fruit ripening (Table 3). In the study, there were significant differences in sugars (sucrose, fructose, and glucose) during the ripening period. Sugar content color (sucrose, glucose fructose, and total sugar) was found to be 262.26, 68.58, 0.00, 330.85 mg/100g in green banana (first stage), 636.07, 113.72, 102.49, 852.28 mg/100g in medium ripe (third stage) banana and 894.58, 293.27, 206.07, 1393.92 mg/100g (fifth stage) in overripe banana. Azman showed increasing sugar content as ripening progressed, being highest when the fruit was fully ripe. Bilgin et al., (2022) examined the sugar content of 'Grand Naine' banana fruits at different ripening stages and found that glucose and fructose values gradually increased in green (first stage), medium ripeness (fourth stage), and extreme ripeness (seventh stage), while sucrose value increased in green (first stage) and extreme ripeness (seventh stage) but decreased in medium ripeness (fourth stage). Fernando et al. (2014) found that the sugar content of Khai banana cultivar increased as ripening progressed and was highest after 8 days of storage. Again, in the study on Hom Thong banana cultivar, they observed that the increases in sugar content occurred during the first 4 days of storage. During ripening, Hom Thong banana cultivar showed the same characteristics as Azman cultivar during ripening. As the banana ripens, starch is converted into sugar and therefore an increase in sugar content occurs, which is a typical characteristic of banana fruit (Valerio-Traya et al., 2002). Cordenunsi and Lajolo (1995) also noticed a significant decrease in starch content accompanying the increase in sugar content. In the study, fructose concentration was lowest and sucrose content was highest in the green and mid-ripening stages, indicating that sucrose dominates glucose and fructose as the rind matures. (Soares et al., 2011). On the other hand, the differences between glucose and sucrose contents are very small at the full maturity stage. The findings of this study are similar to the literature.

Table 3. Shows the results of free sugars in banana samples (mg /100 g fresh weight)

Ripeness stages	Sucrose	Glucose	Fructose	Total sugar
First Stage (Green)	262.26±0.80c	68.58±0.75c	0.00±0.00c	330.85±1.36c
Third Stage (Medium Ripe)	636.07±8.43b	113.72±1.03b	102.49±2.48b	852.28±6.87b
Fifth Stage (Over Ripe)	894.58±1.63a	293.27±1.48a	206.07±1.78a	1393.92±1.31a
Sig	0.00	0.00	0.00	0.00

The difference between means denoted by the same letter is not statistically important ($p<0.05$).

Organic acids are known to affect flavor formation and many physiological processes in fruits depending on the cultivar. Sugar-acid balance and their contents play an important role in determining the taste characteristics of fruits. In this study, oxalic, citric, malic, and succinic acid contents of Azman banana cultivar were analyzed and the results are given in Table 4. According to the results, malic acid is the major organic acid in fruits of banana cultivar. The content of citric, malic, and succinic acids among organic acids in Azman banana increased with fruit ripening while Oxalic acid decreased. Organic acids (citric, malic succinic and oxalic) were found to be 340, 90, 90 mg/100g in green banana (first stage), 370, 340, 90, 40 mg/100g in medium ripe (third stage) banana and 450, 790, 160, 0 mg/100g (fifth stage) in overripe banana. Malic acid content increased during ripening from 280 mg/100 g in green bananas (first stage) to a maximum in ripe bananas (fifth stage). This behavior of malic acid is in good agreement with Wyman and Palmer (1964) and Agravante et al. (1991).

Maduwanthi et al. (2019) found that citric acid was the most abundant organic acid in the green stage (stage 1), while tartaric acid and oxalic acid were found in low amounts of 16.1 ± 2.3 and 30.8 ± 1.6 mg/100 g, respectively, as a result of Ethephon and Acetylene treatments to Ambul banana cultivar. They also reported that citric acid reached the highest level on day 6 (stage 4), while the amount of malic acid was 200.83 ± 2.08 mg/100 g in stage 1 and reached the maximum ripening level on day 8 (stage 6). Kheng et al. (2012) observed that malic, citric, and succinic acids changed during ripening in Rastali banana cultivar at 11 and 12 weeks. Citric and succinic acid levels decreased as bananas harvested at the 11th and 12th weeks ripened and reached the lowest value on day 5. They also found that malic acid levels increased as ripening progressed from day 0 to day 5 for both bananas harvested at two different stages of ripeness. The findings of this study are similar to the literature.

Table 3. Shows the results of organic acids in banana samples (mg / 100 g fresh weight)

Ripeness stages	Citric Acid	Malic Acid	Succinic Acid	Oxalic Acid
First Stage (Green)	340±0.01b	280±0.00c	90±0.00b	90±0.00a
Third Stage (Medium Ripe)	370±0.00b	340±0.00b	90±0.00b	40±0.00b
Fifth Stage (Over Ripe)	450±0.01a	790±0.00a	160±0.00a	0±0.00c
Sig	0.01	0.00	0.00	0.00

The difference between means denoted by the same letter is not statistically important ($p<0.05$).

CONCLUSION

Bananas are of great importance in human nutrition due to their rich content of bioactive compounds such as phenolics, carotenoids, and biogenic amines.Many of these compounds possess antioxidant properties and are effective in protecting the human body against certain oxidative stress conditions. In this study, the "Azman" banana cultivar was used as plant material. This variety holds a high market value due to its aromatic and flavorful nature as well as its durability during transportation.Moreover, the Azman banana variety is more resistant to low temperatures compared to other banana varieties, and its plants are robust and productive. In this study, the rind color, total phenols, antioxidants, sugars, and biochemical contents of the Azman banana cultivar grown in a greenhouse in the Sarıçam district of Adana province in the Mediterranean region were analyzed at different ripening stages using the HPLC technique.The results showed that the L*, a*, and b* color values increased proportionally with the ripening process. Total phenolic content and DPPH radical scavenging activity were found to increase as the fruit ripened. Among the organic acids in Azman bananas, citric, malic, and succinic acid levels increased with ripening, while oxalic acid levels decreased. Additionally, the content of soluble sugars (glucose, sucrose, and fructose) increased significantly during ripening. As ripening progressed, glucose, fructose, sucrose, and total sugar levels showed a sharp increase. The findings indicated that fruits at the fifth ripening stage were richer in biochemical properties and were in their ideal consumption phase.The HPLC technique provided detailed insights into the composition of sugars and organic acids, serving as an effective tool for evaluating the impact of technological processes. This study, which examines the effects of different ripening stages on the bioactive content of the Azman banana cultivar, serves as an important reference source for future research.

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Declaration of Interests

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper

Author Contributions

***1st* Yakup POLAT:**Conceptualization; data curation; formal analysis; funding acquisition
2st Esra EKŞİ : Investigation; methodology; project administration
***3st* N. Ebru KAFKAS:** Software; writing— original draft; writing—review and editing.

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